IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

REQUEST FOR FILING
(RULE 53(b)(1))

For Design or Utility Applications

Rule 53(b)(1) PATENT APPLICATION: **(DO NOT USE FOR CIPs)**

☐ Continuation)
) application under 37 CFR 1.53(b)(1)
☒ Divisional)

application under 37 CFR 1.53(b)(1)
of pending prior application of

Group Art Unit: 2756

Examiner: Romero, A

Inventor(s): FARBER et al.

Parent Appln. No.:	09	021,506	Atty. Dkt.	PM 270531	
	Series Code ⇧	**Serial No. ⇧**		**New M#**	**Client Ref**

Parent Filed: February 10, 1998
This Appln. Filed: July 7, 2000

Title: OPTIMIZED NETWORK RESOURCE LOCATION

Asst. Commissioner of Patents and Trademarks
Washington, DC 20231

Date: July 7, 2000
(Parent Matter No. 214642)

Sir:

To effect the above-requested filing today:

Attached is a copy **(which must be filed)** of the prior application, including:

☒ Abstract
☒ Specification and claims (53 pages) **(must be attached)**
☒ Drawings **(must be attached if originally filed):** 6 sheet(s)/set: ☐ 1 set informal; ☒ Formal of size ☒ A4 ☐ 11"

1A. Always X one box, only:
(1) ☒ Copy of Signed declaration or oath as originally filed in prior application attached
(2) ☐ NO declaration or fee is enclosed; therefore, this is a filing under Rule 53(f).

2. ☐ This application is hereby filed by less than all of the inventors named in the prior application. Petition is hereby made requesting deletion as inventor(s) of the following who is/are **not** inventor(s) of the invention being claimed in this application (DELETE THE FOLLOWING INVENTOR(S)):

1. ______ 2. ______
3. ______ 4. ______
5. ______ 6. ______
7. ______ 8. ______

2.5 THE INVENTOR(S) FOR THIS NEW APPLICATION IS(ARE):

1. ______ 2. ______
3. ______ 4. ______
5. ______ 6. ______
7. ______ 8. ______

3. The entire disclosure of the prior application is considered as being part of the disclosure of the accompanying application and is hereby incorporated therein by reference thereto.

4. ☐ Priority is claimed under 35 U.S.C. 119/365 based on filing in ________________ of
(country)

	Application No.	Filing Date		Application No.	Filing Date
(1)			(2)		
(3)			(4)		
(5)			(6)		

a. ☐ ____________ (No.) Certified copy/copies attached.
b. ☐ Certified copy/copies previously filed on ________________ in
U.S. Application No. _____ / ____________, filed on ______.
series code ⇧ ⇧ serial no.
c. ☐ Certified copy/copies filed during International stage of PCT/ _____ / _____.

4. (a) ☐ Domestic priority is claimed from _____/_____, filed _____.
PCT/
(b) ☐ Benefit is claimed of Provisional Application No. 60/_____, filed _____.

5. ☒ Prior application is assigned to Sandpiper Networks, Inc.

by assignment recorded May 13, 1998 Reel 9208 Frame 0519-21.
(Date)

6. ☒ Attached is the following number of Assignments (including original and all later successive ones by different assignors): 1 and respective **new** Cover Sheets. (Do **NOT** file old cover sheets.)

(Assignments in parent **must be refiled** with new Cover Sheets in this continuing application if you want it/them recorded against the continuing application.)

Please return the recorded Assignment to the undersigned.

7. ☒ The power of attorney in the prior application is to Dale S. Lazar, Reg. No. 28872

(Name and Reg. No.)
whose current address is as in item 8 below.

a. ☒ Recognize as associate attorney Brian Siritzky, Reg. No. 37497

(Name, Reg. No. and Address)

8. **Address all future communications to Intellectual Property Group of Pillsbury Madison & Sutro LLP, Ninth Floor, East Tower 1100 New York Avenue, N.W., Washington, D.C. 20005-3918**

9. ☒ **Amend the specification** by inserting before the first line the sentence:--This is a
☐ continuation ☒ division of Application No. 09/021,506, filed February 10, 1998
series code ⇧ ⇧ serial no.
.--

9. (a) ☐ **Amend the specification** by inserting before the first line: --This application claims the benefit of Provisional Application No. 60/_____, filed _____ .--

10. ☐ It has been recently determined that this new continuing application is entitled to small entity status.
Hence:
___ (No.) Verified Statement(s) establishing "small entity" status under Rules 9 & 27 were/are:
☐ filed in above prior application (and hence applicable hereto)
☐ attached.

11. Petition to extend the life of the above prior application to at least the date hereof
(one box) ☐ is being concurrently filed in that prior application (Use Form PAT-111).
(must be) ☐ was previously filed in that prior application (Check length of prior extension).
(X'd) ☒ is not necessary for copendency (**Double check** before X'ing this box).

12. ☒ **INFORMATION DISCLOSURE STATEMENT:** Attached is Form PTO-1449 listing all of the documents cited by Applicant and the PTO in the parent application(s) relied upon under 35 USC 120 and referenced in item 9 above. Per Rule 98(d) copies of those documents are not required now. Please consider those documents and advise that they have been considered in this new application as by returning a copy of the enclosed Form PTO-1449 with the Examiner's initials in the left column per MPEP 609. .

13. ☐ Attached is a Rule 103(a) Petition to Suspend Action.

14. ☒ **PRELIMINARY AMENDMENT to be entered before fee calculation:** (Do not make amendments here except for correction of improper multiple dependencies or cancellation of whole claims or multiple dependencies for purpose of reducing the filing fee per MPEP §§ 506 and 607; do not cancel all claims).

Please cancel claims 2-24.

FILING FEE

THE FOLLOWING FILING FEE IS BASED ON

->->->->CLAIMS AS FILED AND **CHANGED BY PRELIMINARY AMENDMENT IN ITEM 14**<-<-<-<-

NOTE: If box 1A2 is X'd, do not pay fees, but leave lines 15-22 and 27-32 blank.

				Large/Small Entity		Fee Code
15. Basic Filing Fee .... Design Application				$310/$155		106/26
16. Basic Filing Fee .... Not Design Application				$690/$345	+690	101/201
17. Total Effective Claims	1	minus 20 =	0	x $18/$9	+0	103/203
18. Independent Claims	1	minus 3 =	0	x $78/$39	+0	102/202
19. If any proper multiple dependent claim (ignore improper) is present,				$260/$130	+0	104/204
20.				**Subtotal =**	**$690**	
21. If "petition" box 13 above is X'd, add petition fee. $130					+0	122
21A. If box 6 above is X'd, add Assignment recording fee .... $ 40					+40	581

22. **TOTAL FILING FEE ATTACHED = $730**

(carry forward to Item 31)

23. ☐ ATTACHED:

24. ☒ Preliminary Amendment attached (to be entered after assigning Appln. No.)

25. ☐ The following PRELIMINARY AMENDMENT is to be entered after assigning Appln. No.:

26. **ADDITIONAL FEE CALCULATION FOR PRELIMINARY AMENDMENT <u>PER BOXES 24/25</u>**

		Claims remaining after amendment		Highest number previously paid for		Present Extra		Large/Small Entity		Additional Fee	File Code
27.	Total Effective Claims	*16	minus **	20	=	0	x	$18/$9	=	$ 0	(103/203)
28.	Independent Claims	*5	minus ***	3	=	2	x	$78/$39	=	+ 156	(102/202)

29. If amendment enters proper multiple dependent claim(s) into this application for the first time, add (per application) . . . .$260/$130 + 0 (104/204)

30. ADDITIONAL FEE $ **156**

31. plus **FEE** from item 22 on page 3 + 730

32. **TOTAL FEE ATTACHED** $ **886**

33. *If the entry in this space is less than a entry in the next space, the "Present Extra" result is "0"

34. **If the "Highest number previously paid for" (see item 17 above) is less than 20, write "20" in this space

35. If the "Highest number previously paid for" (see item 18 above) is less than 3, write "3" in this space

Our Deposit Account No. 03-3975

Our Order No.	18404	270531
	C#	M#

CHARGE STATEMENT: Upon the filing of a Declaration pursuant to Rule 60(b) or 60(d), the Commissioner is hereby authorized to charge any fee specifically authorized hereafter, or any missing or insufficient fee(s) filed, or asserted to be filed, or which should have been filed herewith or concerning any paper filed hereafter, and which may be required under Rules 16-18 (missing or insufficient fee only) now or hereafter relative to this application and the resulting Official document under Rule 20, or credit any overpayment, to our Account/Order Nos. shown above for which purpose a duplicate copy of this sheet is attached.
This CHARGE STATEMENT does not authorize charge of the issue fee until/unless an issue fee transmittal form is filed.

Pillsbury Madison & Sutro LLP
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NOTE No. 1: File this Request in duplicate with 2 postcard receipts (PAT-103) & attachments
NOTE No. 2: Is extension in parent necessary for copendency? **DOUBLE CHECK** Item 11 above.
If yes, printout Pat-111 and head it in parent.

In The United States Patent And Trademark Office

In re PATENT APPLICATION of

FARBER et al. Group Art Unit: 2756

Divisional of Appln. No.: 09/021,506 Examiner: Almari ROMERO

Filed: July 7, 2000

For: **Optimized Network Resource Location**

* * * * *

July 7, 2000

Preliminary Amendment

Hon. Commissioner of Patents
and Trademarks
Washington, D.C. 20231

Sir:

Prior to examination of this application, please amend this application as follows:

In The Claims:

Please cancel claim 1 and add the following new claims:

25. (New) A method comprising:

obtaining a first resource containing a reference to a second resource; and

replacing, in the first resource, the reference to the second resource with a different resource reference.

26. (New) A method as in claim 25 wherein the references specify locations of the respective resources on a network.

27. (New) A method as in claim 26 wherein the network is the Internet and wherein the references are uniform resources locators (URLs).

28. (New) A method as in claim 27 wherein the first resource is one of (a) a Hypertext Markup Language (HTML) document and (b) an XML document.

29. (New) A method as in claim 27 wherein the first reference is a URL which refers to a first domain, and wherein the different resource reference refers to a different domain from the first domain.

30. (New) A method as in claim 25 wherein the reference to the second resource is a uniform resource locator (URL) designating a resource on the Internet, and the different resource reference is a different URL.

31. (New) A method as in claim 26 wherein the different URL designates another location for the second resource on the Internet.

32. (New) A method as in claim 25 wherein the first resource is designated by a first uniform resource locator (URL) designating a source/location for the first resource on the Internet, the method further comprising:

replacing the first URL with another different URL; and

providing the other different URL using a REDIRECT message.

33. (New) A method as in claim 25 further comprising:

determining the different resource reference so as to optimize access to the second resource.

34. (New) A method as in claim 33 wherein the different resource reference is determined dynamically.

35. (New) A method comprising:

obtaining an HTML document containing at least one resource reference to a resource on the Internet; and

rewriting the HTML document the reference to replace some resource references in the HTML document with different resource references.

36. (New) A method as in claim 35 wherein the resource references are uniform resources locators (URLs).

37. (New) A method of modifying a resource on a network, where resources on the network are identified by respective resource references, and where the resource contains at least one other resource reference, the method comprising:

replacing at least one of the other resource references in the resource with a different resource reference.

38. (New) A method as in claim 37 wherein the network is the Internet and the resource references are uniform resources locators (URLs).

39. (New) A device comprising:

a mechanism constructed and adapted to obtain a first resource containing a reference to a second resource; and

a mechanism constructed and adapted to replace, in the first resource, the reference to the second resource with a different resource reference.

40. (New) A computer system programmed to:

obtain a first resource containing a reference to a second resource; and

replace, in the first resource, the reference to the second resource with a different resource reference.--

REMARKS

By this Amendment, claim 1 has been cancelled and new claims 25 to 40 have been added.

Applicants respectfully submit that this application is in condition for allowance, and an early action to that effect is earnestly solicited.

Respectfully submitted,

PILLSBURY MADISON & SUTRO, LLP

By ______________________
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OPTIMIZED NETWORK RESOURCE LOCATION

1. Field of the Invention

This invention relates to replication of resources in computer networks.

2. Background of the Invention

The advent of global computer networks, such as the Internet, have led to entirely new and different ways to obtain information. A user of the Internet can now access information from anywhere in the world, with no regard for the actual location of either the user or the information. A user can obtain information simply by knowing a network address for the information and providing that address to an appropriate application program such as a network browser.

The rapid growth in popularity of the Internet has imposed a heavy traffic burden on the entire network. Solutions to problems of demand (e.g., better accessibility and faster communication links) only increase the strain on the supply. Internet Web sites (referred to here as "publishers") must handle ever-increasing bandwidth needs, accommodate dynamic changes in load, and improve performance for distant browsing clients, especially those overseas. The adoption of content-rich applications, such as live audio and video, has further exacerbated the problem.

To address basic bandwidth growth needs, a Web publisher typically subscribes to additional bandwidth from an Internet service provider (ISP), whether in the form of larger or additional "pipes" or channels from the ISP to the publisher's premises, or in the form of large bandwidth commitments in an ISP's remote hosting server collection. These increments are not always as fine-grained as the publisher needs, and quite often lead times can cause the publisher's Web site capacity to lag behind demand.

To address more serious bandwidth growth problems, publishers may develop more complex and costly custom solutions. The solution to the most common need, increasing capacity, is generally based on replication of hardware resources and site

content (known as mirroring), and duplication of bandwidth resources. These solutions, however, are difficult and expensive to deploy and operate. As a result, only the largest publishers can afford them, since only those publishers can amortize the costs over many customers (and Web site hits).

A number of solutions have been developed to advance replication and mirroring. In general, these technologies are designed for use by a single Web site and do not include features that allow their components to be shared by many Web sites simultaneously.

Some solution mechanisms offer replication software that helps keep mirrored servers up-to-date. These mechanisms generally operate by making a complete copy of a file system. One such system operates by transparently keeping multiple copies of a file system in synch. Another system provides mechanisms for explicitly and regularly copying files that have changed. Database systems are particularly difficult to replicate, as they are continually changing. Several mechanisms allow for replication of databases, although there are no standard approaches for accomplishing it. Several companies offering proxy caches describe them as replication tools. However, proxy caches differ because they are operated on behalf of clients rather than publishers.

Once a Web site is served by multiple servers, a challenge is to ensure that the load is appropriately distributed or balanced among those servers. Domain name-server-based round-robin address resolution causes different clients to be directed to different mirrors.

Another solution, load balancing, takes into account the load at each server (measured in a variety of ways) to select which server should handle a particular request.

Load balancers use a variety of techniques to route the request to the appropriate server. Most of those load-balancing techniques require that each server be an exact replica of the primary Web site. Load balancers do not take into account the "network distance" between the client and candidate mirror servers.

Assuming that client protocols cannot easily change, there are two major problems in the deployment of replicated resources. The first is how to select which copy of the resource to use. That is, when a request for a resource is made to a single server, how should the choice of a replica of the server (or of that data) be made. We call this problem the "rendezvous problem". There are a number of ways to get clients to rendezvous at distant mirror servers. These technologies, like load balancers, must route a request to an appropriate server, but unlike load balancers, they take network performance and topology into account in making the determination.

A number of companies offer products which improve network performance by prioritizing and filtering network traffic.

Proxy caches provide a way for client aggregators to reduce network resource consumption by storing copies of popular resources close to the end users. A client aggregator is an Internet service provider or other organization that brings a large number of clients operating browsers to the Internet. Client aggregators may use proxy caches to reduce the bandwidth required to serve web content to these browsers. However, traditional proxy caches are operated on behalf of Web clients rather than Web publishers.

Proxy caches store the most popular resources from all publishers, which means they must be very large to achieve reasonable cache efficiency. (The efficiency of a cache is defined as the number of requests for resources which are already cached divided by the total number of requests.)

Proxy caches depend on cache control hints delivered with resources to determine when the resources should be replaced. These hints are predictive, and are necessarily often incorrect, so proxy caches frequently serve stale data. In many cases, proxy cache operators instruct their proxy to ignore hints in order to make the cache more efficient, even though this causes it to more frequently serve stale data.

Proxy caches hide the activity of clients from publishers. Once a resource is cached, the publisher has no way of knowing how often it was accessed from the cache.

SUMMARY OF THE INVENTION

This invention provides a way for servers in a computer network to off-load their processing of requests for selected resources by determining a different server (a "repeater") to process those requests. The selection of the repeater can be made dynamically, based on information about possible repeaters.

If a requested resource contains references to other resources, some or all of these references can be replaced by references to repeaters.

Accordingly, in one aspect, this invention is a method of processing resource requests in a computer network. First a client makes a request for a particular resource from an origin server, the request including a resource identifier for the particular resource, the resource identifier sometimes including an indication of the origin server. Requests arriving at the origin server do not always include an indication of the origin server; since they are sent to the origin server, they do not need to name it. A mechanism referred to as a reflector, co-located with the origin server, intercepts the request from the client to the origin server and decides whether to reflect the request or to handle it locally. If the reflector decides to handle the request locally, it forwards it to the origin server, otherwise it selects a "best" repeater to process the request. If the request is reflected, the client is provided with a modified resource identifier designating the repeater.

The client gets the modified resource identifier from the reflector and makes a request for the particular resource from the repeater designated in the modified resource identifier.

When the repeater gets the client's request, it responds by returning the requested resource to the client. If the repeater has a local copy of the resource then it returns that copy, otherwise it forwards the request to the origin server to get the resource, and saves a local copy of the resource in order to serve subsequent requests.

The selection by the reflector of an appropriate repeater to handle the request can be done in a number of ways. In the preferred embodiment, it is done by first pre-

partitioning the network into "cost groups" and then determining which cost group the client is in. Next, from a plurality of repeaters in the network, a set of repeaters is selected, the members of the set having a low cost relative to the cost group which the client is in. In order to determine the lowest cost, a table is maintained and regularly updated to define the cost between each group and each repeater. Then one member of the set is selected, preferably randomly, as the best repeater.

If the particular requested resource itself can contain identifiers of other resources, then the resource may be rewritten (before being provided to the client). In particular, the resource is rewritten to replace at least some of the resource identifiers contained therein with modified resource identifiers designating a repeater instead of the origin server. As a consequence of this rewriting process, when the client requests other resources based on identifiers in the particular requested resource, the client will make those requests directly to the selected repeater, bypassing the reflector and origin server entirely.

Resource rewriting must be performed by reflectors. It may also be performed by repeaters, in the situation where repeaters "peer" with one another and make copies of resources which include rewritten resource identifiers that designate a repeater.

In a preferred embodiment, the network is the Internet and the resource identifier is a uniform resource locator (URL) for designating resources on the Internet, and the modified resource identifier is a URL designating the repeater and indicating the origin server (as described in step B3 below), and the modified resource identifier is provided to the client using a REDIRECT message. Note, only when the reflector is "reflecting" a request is the modified resource identifier provided using a REDIRECT message.

In another aspect, this invention is a computer network comprising a plurality of origin servers, at least some of the origin servers having reflectors associated therewith, and a plurality of repeaters.

Brief Description of the Drawings

The above and other objects and advantages of the invention will be apparent upon consideration of the following detailed description, taken in conjunction with the accompanying drawings, in which the reference characters refer to like parts throughout and in which:

Figure 1 depicts a portion of a network environment according to the present invention; and

Figures 2-6 are flow charts of the operation of the present invention.

Detailed Description of the Presently Preferred Exemplary Embodiments

Overview

Figure 1 shows a portion of a network environment **100** according to the present invention, wherein a mechanism (reflector **108**, described in detail below) at a server (herein origin server **102**) maintains and keeps track of a number of partially replicated servers or repeaters **104a**, **104b**, and **104c**. Each repeater **104a**, **104b**, and **104c** replicates some or all of the information available on the origin server **102** as well as information available on other origin servers in the network **100**. Reflector **108** is connected to a particular repeater known as its "contact" repeater ("Repeater B" **104b** in the system depicted in **Figure 1**). Preferably each reflector maintains a connection with a single repeater known as its contact, and each repeater maintains a connection with a special repeater known as its master repeater (e.g., repeater **104m** for repeaters **104a**, **104b** and **104c** in **Figure 1**).

Thus, a repeater can be considered as a dedicated proxy server that maintains a partial or sparse mirror of the origin server **102**, by implementing a distributed coherent cache of the origin server. A repeater may maintain a (partial) mirror of more than one origin server. In some embodiments, the network **100** is the Internet and repeaters

mirror selected resources provided by origin servers in response to clients' HTTP (hypertext transfer protocol) and FTP (file transfer protocol) requests.

A client **106** connects, via the network **100**, to origin server **102** and possibly to one or more repeaters **104a** etc.

Origin server **102** is a server at which resources originate. More generally, the origin server **102** is any process or collection of processes that provide resources in response to requests from a client **106**. Origin server **102** can be any off-the-shelf Web server. In a preferred embodiment, origin server **102** is typically a Web server such as the Apache server or Netscape Communications Corporation's Enterprise™ server.

Client **106** is a processor requesting resources from origin server **102** on behalf of an end user. The client **106** is typically a user agent (e.g., a Web browser such as Netscape Communications Corporation's Navigator™) or a proxy for a user agent. Components other than the reflector **108** and the repeaters **104a, 104b,** etc., may be implemented using commonly available software programs. In particular, this invention works with any HTTP client (e.g., a Web browser), proxy cache, and Web server. In addition, the reflector **108** might be fully integrated into the data server **112** (for instance, in a Web Server). These components might be loosely integrated based on the use of extension mechanisms (such as so-called add-in modules) or tightly integrated by modifying the service component specifically to support the repeaters.

Resources originating at the origin server **102** may be static or dynamic. That is, the resources may be fixed or they may be created by the origin server **102** specifically in response to a request. Note that the terms "static" and "dynamic" are relative, since a static resource may change at some regular, albeit long, interval.

Resource requests from the client **106** to the origin server **102** are intercepted by reflector **108** which for a given request either forwards the request on to the origin server **102** or conditionally reflects it to some repeater **104a, 104b,** etc. in the network **100**. That is, depending on the nature of the request by the client **106** to the origin server **102**, the reflector **108** either serves the request locally (at the origin server **102**), or selects one

of the repeaters (preferably the best repeater for the job) and reflects the request to the selected repeater. In other words, the reflector **108** causes requests for resources from origin server **102**, made by client **106**, to be either served locally by the origin server **102** or transparently reflected to the best repeater **104a, 104b**, etc. The notion of a best repeater and the manner in which the best repeater is selected are described in detail below.

Repeaters **104a, 104b**, etc. are intermediate processors used to service client requests thereby improving performance and reducing costs in the manner described herein. Within repeaters **104a, 104b**, etc., are any processes or collections of processes that deliver resources to the client **106** on behalf of the origin server **102**. A repeater may include a repeater cache **110**, used to avoid unnecessary transactions with the origin server **102**.

The reflector **108** is a mechanism, preferably a software program, that intercepts requests that would normally be sent directly to the origin server **102**. While shown in the drawings as separate components, the reflector **108** and the origin server **102** are typically co-located, e.g., on a particular system such as data server **112**. (As discussed below, the reflector **108** may even be a "plug in" module that becomes part of the origin server **102**.

FIGURE 1 shows only a part of a network **100** according to this invention. A complete operating network consists of any number of clients, repeaters, reflectors, and origin servers. Reflectors communicate with the repeater network, and repeaters in the network communicate with one another.

Uniform Resource Locators

Each location in a computer network has an address which can generally be specified as a series of names or numbers. In order to access information, an address for that information must be known. For example, on the World Wide Web ("the Web") which is a subset of the Internet, the manner in which information address locations are

provided has been standardized into Uniform Resource Locators (URLs). URLs specify the location of resources (information, data files, etc.) on the network.

The notion of URLs becomes even more useful when hypertext documents are used. A hypertext document is one which includes, within the document itself, links (pointers or references) to the document itself or to other documents. For example, in an on-line legal research system, each case may be presented as a hypertext document. When other cases are cited, links to those cases can be provided. In this way, when a person is reading a case, they can follow cite links to read the appropriate parts of cited cases.

In the case of the Internet in general and the World Wide Web specifically, documents can be created using a standardized form known as the Hypertext Markup Language (HTML). In HTML, a document consists of data (text, images, sounds, and the like), including links to other sections of the same document or to other documents. The links are generally provided as URLs, and can be in relative or absolute form. Relative URLs simply omit the parts of the URL which are the same as for the document including the link, such as the address of the document (when linking to the same document), etc. In general, a browser program will fill in missing parts of a URL using the corresponding parts from the current document, thereby forming a fully formed URL including a fully qualified domain name, etc.

A hypertext document may contain any number of links to other documents, and each of those other documents may be on a different server in a different part of the world. For example, a document may contain links to documents in Russia, Africa, China and Australia. A user viewing that document at a particular client can follow any of the links transparently (i.e., without knowing where the document being linked to actually resides). Accordingly, the cost (in terms of time or money or resource allocation) of following one link versus another may be quite significant.

URLs generally have the following form (defined in detail in T. Berners-Lee et al, *Uniform Resource Locators (URL)*, Network Working Group, Request for Comments: 1738,

Category: Standards Track, December 1994, located at "http://ds.internic.net/rfc/rfc1738.txt", which is hereby incorporated herein by reference):

scheme://host[:port]/url-path

where "scheme" can be a symbol such as *"file"* (for a file on the local system), *"ftp"* (for a file on an anonymous FTP file server), *"http"* (for a file on a file on a Web server),and *"telnet"* (for a connection to a Telnet-based service). Other schemes, can also be used and new schemes are added every now and then. The port number is optional, the system substituting a default port number (depending on the scheme) if none is provided. The "host" field maps to a particular network address for a particular computer. The "url-path" is relative to the computer specified in the "host" field. A url-path is typically, but not necessarily, the pathname of a file in a web server directory.

For example, the following is a URL identifying a file "F" in the path "A/B/C" on a computer at *"www.uspto.gov"*:

http://www.uspto.gov/A/B/C/F

In order to access the file "F" (the resource) specified by the above URL, a program (e.g., a browser) running on a user's computer (i.e., a client computer) would have to first locate the computer (i.e., a server computer) specified by the host name. I.e., the program would have to locate the server *"www.uspto.gov"*. To do this, it would access a Domain Name Server (DNS), providing the DNS with the host name (*"www.uspto.gov"*). The DNS acts as a kind of centralized directory for resolving addresses from names. If the DNS determines that there is a (remote server) computer corresponding to the name *"www.uspto.gov"*, it will provide the program with an actual computer network address for that server computer. On the Internet this is called an Internet Protocol (or IP) address and it has the form "123.345.456.678". The program on the user's (client) computer would then use the actual address to access the remote (server) computer.

The program opens a connection to the HTTP server (Web server) on the remote computer "*www.uspto.gov*" and uses the connection to send a request message to the remote computer (using the HTTP scheme). The message is typically an HTTP GET request which includes the url-path of the requested resource, "A/B/C/F". The HTTP server receives the request and uses it to access the resource specified by the url-path "A/B/C/F". The server returns the resource over the same connection.

Thus, conventionally HTTP client requests for Web resources at an origin server **102** are processed as follows (see **FIGURE 2**) (This is a description of the process when no reflector **108** is installed.):

A1. A browser (e.g., Netscape's Navigator) at the client receives a resource identifier (i.e., a URL) from a user.

A2. The browser extracts the host (origin server) name from the resource identifier, and uses a domain name server (DNS) to look up the network (IP) address of the corresponding server. The browser also extracts a port number, if one is present, or uses a default port number (the default port number for http requests is 80).

A3. The browser uses the server's network address and port number to establish a connection between the client **106** and the host or origin server **102**.

A4. The client **106** then sends a (GET) request over the connection identifying the requested resource.

A5. The origin server **102** receives the request and

A6. locates or composes the corresponding resource.

A7. The origin server **102** then sends back to the client **106** a reply containing the requested resource (or some form of error indicator if the resource is unavailable). The reply is sent to the client over the same connection as that on which the request was received from the client.

A8. The client **106** receives the reply from the origin server **102.**

There are many variations of this basic model. For example, in one variation, instead of providing the client with the resource, the origin server can tell the client to re-request the resource by another name. To do so, in A7 the server **102** sends back to the client **106** a reply called a "REDIRECT" which contains a new URL indicating the other name. The client **106** then repeats the entire sequence, normally without any user intervention, this time requesting the resource identified by the new URL.

System Operation

In this invention reflector **108** effectively takes the place of an ordinary Web server or origin server **102.** The reflector **108** does this by taking over the origin server's IP address and port number. In this way, when a client tries to connect to the origin server **102,** it will actually connect to the reflector **108.** The original Web server (or origin server **102**) must then accept requests at a different network (IP) address, or at the same IP address but on a different port number. Thus, using this invention, the server referred to in A3-A7 above is actually a reflector **108.**

Note that it is also possible to leave the origin server's network address as it is and to let the reflector run at a different address or on a different port. In this way the reflector does not intercept requests sent to the origin server, but can still be sent requests addressed specifically to the reflector. Thus the system can be tested and configured without interrupting its normal operation.

The reflector **108** supports the processing as follows (see **FIGURE 3**):
upon receipt of a request,

B1 The reflector **108** analyzes the request to determine whether or not to reflect the request. To do this, first the reflector determines whether the sender (client **106**) is a browser or a repeater. Requests issued by repeaters must be served locally by the origin server **102**. This determination can be made by looking up the network (IP) address of the sender in a list of known repeater network (IP) addresses. Alternatively, this determination could be made by attaching information to a request to indicate that the request is from a specific repeater, or repeaters can request resources from a special port other than the one used for ordinary clients.

B2 If the request is not from a repeater, the reflector looks up the requested resource in a table (called the "rule base") to determine whether the resource requested is "repeatable". Based on this determination, the reflector either reflects the request (B3, described below) or serves the request locally (B4, described below).

The rule base is a list of regular expressions and associated attributes. (Regular expressions are well-known in the field of computer science. A small bibliography of their use is found in *Aho, et al.*, "Compilers, Principles, techniques and tools", Addison-Wesley, 1986, pp. 157-158.) The resource identifier (URL) for a given request is looked up in the rule base by matching it sequentially with each regular expression. The first match identifies the attributes for the resource, namely repeatable or local. If there is no match in the rule base, a default attribute is used. Each reflector has its own rule base, which is manually configured by the reflector operator.

B3. To reflect a request, (to serve a request locally go to B4), as shown in **FIGURE 4**, the reflector determines (B3-1) the best repeater to reflect the request to, as described in detail below. The reflector then creates (B3-2) a new resource identifier (URL) (using the requested URL and the best repeater) that identifies the same resource at the selected repeater.

It is necessary that the reflection step create a single URL containing the URL of the original resource, as well as the identity of the selected repeater. A special form of URL is created to provide this information. This is done by creating a new URL as follows:

D1. Given a repeater name, scheme, origin server name and path, create a new URL. If the scheme is "http", the preferred embodiment uses the following format:

http://<repeater>/<server>/<path>

If the form used is other than "http", the preferred embodiment uses the following format:

http://<repeater>/<server>@proxy=<scheme>@/<path>

The reflector can also attach a MIME type to the request, to cause the repeater to provide that MIME type with the result. This is useful because many protocols (such as FTP) do not provide a way to attach a MIME type to a resource. The format is

http://<repeater>/<server>@proxy=<scheme>:<type>@/<path>

This URL is interpreted when received by the repeater.

The reflector then sends (B3-3) a REDIRECT reply containing this new URL to the requesting client. The HTTP REDIRECT command allows the reflector to send the browser a single URL to retry the request.

B4. To serve a request locally, the request is sent by the reflector to ("forwarded to") the origin server **102**. In this mode, the reflector acts as a reverse proxy server. The origin server **102** processes the request in the normal manner (A5-A7). The reflector then obtains the origin server's reply to the request which it inspects to determine if the requested resource is an HTML document, i.e., whether the requested resource is one which itself contains resource identifiers.

B5. If the resource is an HTML document then the reflector rewrites the HTML document by modifying resource identifiers (URLs) within it, as described below. The resource, possibly as modified by rewriting, is then returned in a reply to the requesting client **106**.

If the requesting client is a repeater, the reflector may temporarily disable any cache-control modifiers which the origin server attached to the reply. These disabled cache-control modifiers are later re-enabled when the content is served from the repeater. This mechanism makes it possible for the origin server to prevent resources from being cached at normal proxy caches, without affecting the behavior of the cache at the repeater.

B6. Whether the request is reflected or handled locally, details about the transaction, such as the current time, the address of the requester, the URL requested, and the type of response generated, are written by the

reflector to a local log file.

By using a rule base (B2), it is possible to selectively reflect resources. There are a number of reasons that certain particular resources cannot be effectively repeated (and therefore should not be reflected), for instance:

- the resource is composed uniquely for each request;
- the resource relies on a so-called cookie (browsers will not send cookies to repeaters with different domain names);
- the resource is actually a program (such as a Java applet) that will run on the client and that wishes to connect to a service (Java requires that the service be running on the same machine that provided the applet).

In addition, the reflector **108** can be configured so that requests from certain network addresses (e.g., requests from clients on the same local area network as the reflector itself) are never reflected. Also, the reflector may choose not to reflect requests because the reflector is exceeding its committed aggregate information rate, as described below.

A request which is reflected is automatically mirrored at the repeater when the repeater receives and processes the request.

The combination of the reflection process described here and the caching process described below effectively creates a system in which repeatable resources are migrated to and mirrored at the selected reflector, while non-repeatable resources are not mirrored.

Alternate Approach

Placing the origin server name in the reflected URL is generally a good strategy, but it may be considered undesirable for aesthetic or (in the case, e.g., of cookies) certain technical reasons.

It is possible to avoid the need for placing both the repeater name and the server name in the URL. Instead, a "family" of names may be created for a given origin server, each name identifying one of the repeaters used by that server.

For instance, if www.example.com is the origin server, names for three repeaters might be created:

wr1.example.com
wr2.example.com
wr3.example.com

The name "wr1.example.com" would be an alias for repeater 1, which might also be known by other names such as "wr1.anotherExample.com" and "wr1.example.edu".

If the repeater can determine by which name it was addressed, it can use this information (along with a table that associates repeater alias names with origin server names) to determine which origin server is being addressed. For instance, if repeater 1 is addressed as wr1.example.com, then the origin server is "www.example.com"; if it is addressed as "wr1.anotherExample.com", then the origin server is "www.anotherExample.com".

The repeater can use two mechanisms to determine by which alias it is addressed:

1. Each alias can be associated with a different IP address. Unfortunately, this solution does not scale well, as IP addresses are currently scarce, and the number of IP addresses required grows as the product of origin servers and repeaters.
2. The repeater can attempt to determine the alias name used by inspecting the "host:" tag in the HTTP header of the request. Unfortunately, some old browsers still in use do not attach the "host:" tag to a request. Reflectors would need to identify such browsers (the browser identity is a part of each request) and avoid this form of reflection.

How a Repeater Handles a Request

When a browser receives a REDIRECT response (as produced in B3), it reissues

a request for the resource using the new resource identifier (URL) (A1-A5). Because the new identifier refers to a repeater instead of the origin server, the browser now sends a request for the resource to the repeater which processes a request as follows, with reference to **FIGURE 5**:

C1. First the repeater analyzes the request to determine the network address of the requesting client and the path of the resource requested. Included in the path is an origin server name (as described above with reference to B3).

C2. The repeater uses an internal table to verify that the origin server belongs to a known "subscriber". A subscriber is an entity (e.g., a company) that publishes resources (e.g., files) via one or more origin servers. When the entity subscribes, it is permitted to utilize the repeater network. The subscriber tables described below include the information that is used to link reflectors to subscribers.

If the request is not for a resource from a known subscriber, the request is rejected. To reject a request, the repeater returns a reply indicating that the requested resource does not exist.

C3. The repeater then determines whether the requested resource is cached locally. If the requested resource is in the repeater's cache it is retrieved. On the other hand, if a valid copy of the requested resource is not in the repeater's cache, the repeater modifies the incoming URL, creating a request that it issues directly to the originating reflector which processes it (as in B1-B6). Because this request to the originating reflector is from a repeater, the reflector always returns the requested resource rather than reflecting the request. (Recall that reflectors always handle requests from repeaters locally.) If the repeater obtained the resource from the origin

server, the repeater then caches the resource locally.

If a resource is not cached locally, the cache can query its "peer caches" to see if one of them contains the resource, before or at the same time as requesting the resource from the reflector/origin server. If a peer cache responds positively in a limited period of time (preferably a small fraction of a second), the resource will be retrieved from the peer cache.

C4. The repeater then constructs a reply including the requested resource (which was retrieved from the cache or from the origin server) and sends that reply to the requesting client.

C5. Details about the transaction, such as the associated reflector, the current time, the address of the requester, the URL requested, and the type of response generated, are written to a local log file at the repeater.

Note that the bottom row of **FIGURE 2** refers to an origin server, or a reflector, or a repeater, depending on what the URL in step A1 identifies.

Selecting the Best Repeater

If the reflector **108** determines that it will reflect the request, it must then select the best repeater to handle that request (as referred to in step B3-1). This selection is performed by the Best Repeater Selector (BRS) mechanism described here.

The goal of the BRS is to select, quickly and heuristically, an appropriate repeater for a given client given only the network address of the client. An appropriate repeater is one which is not too heavily loaded and which is not too far from the client in terms

of some measure of network distance. The mechanism used here relies on specific, compact, pre-computed data to make a fast decision. Other, dynamic solutions can also be used to select an appropriate repeater.

The BRS relies on three pre-computed tables, namely the Group Reduction Table, the Link Cost Table, and the Load Table. These three tables (described below) are computed off-line and downloaded to each reflector by its contact in the repeater network.

The Group Reduction Table places every network address into a group, with the goal that addresses in a group share relative costs, so that they would have the same best repeater under varying conditions (i.e., the BRS is invariant over the members of the group). .

The Link Cost Table is a two dimensional matrix which specifies the current cost between each repeater and each group. Initially, the link cost between a repeater and a group is defined as the "normalized link cost" between the repeater and the group, as defined below. Over time, the table will be updated with measurements which more accurately reflect the relative cost of transmitting a file between the repeater and a member of the group. The format of the Link Cost Table is <Group ID> <Group ID> <link cost>, where the Group ID's are given as AS numbers.

The Load Table is a one dimensional table which identifies the current load at each repeater. Because repeaters may have different capacities, the load is a value that represents the ability of a given repeater to accept additional work. Each repeater sends its current load to a central master repeater at regular intervals, preferably at least approximately once a minute. The master repeater broadcasts the Load Table to each reflector in the network, via the contact repeater.

A reflector is provided entries in the Load Table only for repeaters which it is assigned to use. The assignment of repeaters to reflectors is performed centrally by a repeater network operator at the master repeater. This assignment makes it possible to modify the service level of a given reflector. For instance, a very active reflector may use

many repeaters, whereas a relatively inactive reflector may use few repeaters.

Tables may also be configured to provide selective repeater service to subscribers in other ways, e.g., for their clients in specific geographic regions, such as Europe or Asia.

Measuring Load

In the presently preferred embodiments, repeater load is measured in two dimensions, namely

1. requests received by the repeater per time interval *(RRPT)*, and
2. bytes sent by the repeater per time interval *(BSPT)*.

For each of these dimensions, a maximum *capacity* setting is set. The maximum capacity indicates the point at which the repeater is considered to be fully loaded. A higher RRPT capacity generally indicates a faster processor, whereas a higher BSPT capacity generally indicates a wider network pipe. This form of load measurement assumes that a given server is dedicated to the task of repeating.

Each repeater regularly calculates its *current* RRPT and BSPT, by accumulating the number of requests received and bytes sent over a short time interval. These measurements are used to determine the repeater's load in each of these dimensions. If a repeater's load exceeds its configured capacity, an alarm message is sent to the repeater network administrator.

The two current load components are combined into a single value indicating overall current load. Similarly, the two maximum capacity components are combined into a single value indicating overall maximum capacity. The components are combined as follows:

$$\text{current-load} = B \times \text{current RRPT} + (1 - B) \times \text{current BSPT}$$

$$\text{max-load} = B \times \text{max RRPT} + (1 - B) \times \text{max BSPT}$$

The factor B, a value between 0 and 1, allows the relative weights of RRPT and BSPT to be adjusted, which favors consideration of either processing power or

bandwidth.

The overall current load and overall maximum capacity values are periodically sent from each repeater to the master repeater, where they are aggregated in the Load Table, a table summarizing the overall load for all repeaters. Changes in the Load Table are distributed automatically to each reflector.

While the preferred embodiment uses a two-dimensional measure of repeater load, any other measure of load can be used.

Combining Link Costs and Load

The BRS computes the cost of servicing a given client from each eligible repeater. The cost is computed by combining the available capacity of the candidate repeater with the cost of the link between that repeater and the client. The link cost is computed by simply looking it up in the Link Cost table.

The cost is determined using the following formula:

*threshold = K * max-load*
capacity = max(max-load - current-load, e)
capacity = min(capacity, threshold)
*cost = link-cost * threshold / capacity*

In this formula, *e* is a very small number (epsilon) and *K* is a tuning factor initial set to 0.5. This formula causes the cost to a given repeater to be increased, at a rate defined by *K*, if its capacity falls below a configurable threshold.

Given the cost of each candidate repeater, the BRS selects all repeaters within a delta factor of the best score. From this set, the result is selected at random.

The delta factor prevents the BRS from repeatedly selecting a single repeater when scores are similar. It is generally required because available information about load

and link costs loses accuracy over time. This factor is tunable.

Best Repeater Selector (BRS)

The BRS operates as follows, with reference to **FIGURE 6**:

Given a client network address and the three tables described above:

E1. Determine which group the client is in using the Group Reduction Table.

E2. For each repeater in the Link Cost Table and Load Table, determine that repeater's combined cost as follows:

E2a. Determine the maximum and current load on the repeater (using the Load Table).

E2b. Determine the link cost between the repeater and the client's group (using the Link Cost Table).

E2c. Determine the combined cost as described above.

E3. Select a small set of repeaters with the lowest cost.

E4. Select a random member from the set.

Preferably the results of the BRS processing are maintained in a local cache at the reflector **108**. Thus, if the best repeater has recently been determined for a given client (i.e., for a given network address), that best repeater can be reused quickly without being re-determined. Since the calculation described above is based on statically, pre-computed tables, if the tables have not changed then there is no need to re-determine the best repeater.

Determining the Group Reduction and Link Cost Tables

The Group Reduction Table and Link Cost Table used in BRS processing are created and regularly updated by an independent procedure referred to herein as *NetMap*. The *NetMap* procedure is run by executing several phases (described below) as needed.

The term *Group* is used here to refers to an IP "address group".

The term *Repeater Group* refers to a Group that contains the IP address of a repeater.

The term *link cost* refers to a statically determined cost for transmitting data between two Groups. In a presently preferred implementation, this is the minimum of the sums of the costs of the links along each path between them. The link costs of primary concern here are link costs between a Group and a Repeater Group.

The term *relative link cost* refers to the link cost relative to other link costs for the same Group which is calculated by subtracting the minimum link cost from a Group to any Repeater Group from each of its link costs to a Repeater Group.

The term Cost Set refers to a set of Groups that are equivalent in regard to Best Repeater Selection. That is, given the information available, the same repeater would be selected for any of them.

The *NetMap* procedure first processes input files to create an internal database called the Group Registry. These input files describe groups, the IP addresses within groups, and links between groups, and come a variety of sources, including publicly available Internet Routing Registry (IRR) databases, BGP router tables, and probe services that are located at various points around the Internet and use publicly available tools (such as "traceroute") to sample data paths. Once this processing is complete, the Group Registry contains essential information used for further processing, namely (1) the identity of each group, (2) the set of IP addresses in a given group, (3) the presence of links between groups indicating paths over which information may travel, and (4) the

cost of sending data over a given link.

The following processes are then performed on the Group Registry file.

Calculate Repeater Group link costs

The *NetMap* procedure calculates a "link cost" for transmission of data between each Repeater Group and each Group in the Group Registry. This overall link cost is defined as the minimum cost of any path between the two groups, where the cost of a path is equal to the sum of the costs of the individual links in the path. The link cost algorithm presented below is essentially the same as algorithm #562 from ACM journal Transactions on Mathematical Software: "Shortest Path From a Specific Node to All Other Nodes in a Network" by U. Pape, ACM TOMS 6 (1980) pp. 450-455, http://www.netlib.org/toms/562.

In this processing, the term Repeater Group refers to a Group that contains the IP address of a repeater. A group is a neighbor of another group if the Group Registry indicates that there is a link between the two groups.

For each target Repeater Group **T**:

- Initialize the link cost between **T** and itself to zero.
- Initialize the link cost between **T** and every other Group to infinity.
- Create a list **L** that will contain Groups that are equidistant from the target Repeater Group **T**.
- Initialize the list **L** to contain just the target Repeater Group **T** itself.
- While the list **L** is not empty:
    - Create an empty list **L'** of neighbors of members of the list **L**.
    - For each Group **G** in the list **L**:
        - For each Group **N** that is a neighbor of **G**:
            - Let **cost** refer to the sum of the link cost between **T** and **G**, and the link cost between **G** and **N**.

The cost between **T** and **G** was determined in the previous pass of the algorithm; the link cost between **G** and **N** is from the Group Registry.

- If **cost** is less than the link cost between **T** and **N**:
    - Set the link cost between **T** and **N** to **cost**.
    - Add **N** to **L'** if it is not already on it.
- Set **L** to **L'**.

Calculate Cost Sets

A Cost Set is a set of Groups that are equivalent with respect to Best Repeater Selection. That is, given the information available, the same repeater would be selected for any of them.

The "cost profile" of a Group G is defined herein as the set of costs between G and each Repeater. Two cost profiles are said to be equivalent if the values in one profile differ from the corresponding values in the other profile by a constant amount.

Once a client Group is known, the Best Repeater Selection algorithm relies on the cost profile for information about the Group. If two cost profiles are equivalent, the BRS algorithm would select the same repeater given either profile.

A Cost Set is then a set of groups that have equivalent cost profiles.

The effectiveness of this method can be seen, for example, in the case where all paths to a Repeater from some Group A pass through some other Group B. The two Groups have equivalent cost profiles (and are therefore in the same Cost Set) since whatever Repeater is best for Group A is also going to be best for Group B, regardless of what path is taken between the two Groups.

By normalizing cost profiles, equivalent cost profiles can be made identical. A normalized cost profile is a cost profile in which the minimum cost has the value zero. A normalized cost profile is computed by finding the minimum cost in the profile, and subtracting that value from each cost in the profile.

Cost Sets are then computed using the following algorithm:

- For each Group **G**:
    - Calculate the normalized cost profile for **G**
    - Look for a Cost Set with the same normalized cost profile.
    - If such as set is found, add **G** to the existing Cost Set;
    - otherwise, create a new Cost Set with the calculated normalized cost profile, containing only **G**.

The algorithm for finding Cost Sets employs a hash table to reduce the time necessary to determine whether the desired Cost Set already exists. The hash table uses a hash value computed from cost profile of **G**.

Each Cost Set is then numbered with a unique Cost Sent Index number. Cost Sets are then used in a straightforward manner to generate the Link Cost Table, which gives the cost from each Cost Set to each Repeater.

As described below, the Group Reduction Table maps every IP address to one of these Cost Sets.

Build IP Map

The IP Map is a sorted list of records which map IP address ranges to Link Cost Table keys. The format of the IP map is:

<base IP address> <max IP address> <Link Cost Table key>

where IP addresses are presently represented by 32-bit integers. The entries are sorted by descending base address, and by ascending maximum address among equal base addresses, and by ascending Link Cost Table key among equal base addresses and maximum addresses. Note that ranges may overlap.

The *NetMap* procedure generates an intermediate IP map containing a map between IP address ranges and Cost Set numbers as follows:

- For each Cost Set **S**:
    - For each Group **G** in **S**:
        - For each IP address range in **G**:
            - Add a triple (low address, high address, Cost Set number of **S**) to the IP map.

The IP map file is then sorted by descending base address, and by ascending maximum address among equal base addresses, and by ascending Cost Set number among equal base addresses and maximum addresses. The sort order for the base address and maximum address minimizes the time to build the Group Reduction Table and produces the proper results for overlapping entries.

Finally, the *NetMap* procedure creates the Group Reduction Table by processing the sorted IP map. The Group Reduction Table maps IP addresses (specified by ranges) into Cost Set numbers. Special processing of the IP map file is required in order to detect overlapping address ranges, and to merge adjacent address ranges in order to minimize the size of the Group Reduction Table.

An ordered list of address range segments is maintained, each segment consisting of a base address **B** and a Cost Set number **N**, sorted by base address **B**. (The maximum address of a segment is the base address of the next segment minus one.)

The following algorithm is used:

- Initialize the list with the elements [-infinity, NOGROUP], [+infinity, NOGROUP].
    - For each entry in the IP map, in sorted order, consisting of (b, m, s),
        - Insert (b, m, s) in the list (recall that IP map entries are of the form (low address, high address Cost Set number of S))
    - For each reserved LAN address range (b, m):

Insert (b, m, LOCAL) in the list.

- For each Repeater at address a:

  Insert (a, a, REPEATER) in the list.

- For each segment **S** in the ordered list:
  - Merge **S** with following segments with the same Cost Set
  - Create a Group Reduction Table entry with base address from the base address of **S**,
    - max address = next segment's base – 1,
    - group ID = Cost Set number of **S**.

A reserved LAN address range is an address range reserved for use by LANs which should not appear as a global Internet address. LOCAL is a special Cost Set index different from all others, indicating that the range maps to a client which should never be reflected. REPEATER is a special Cost Set index different from all others, indicating that the address range maps to a repeater. NOGROUP is a special Cost Set index different from all others, indicating that this range of addresses has no known mapping.

Given (**B**, **M**, **N**), insert an entry in the ordered address list as follows:

Find the last segment (AB, AN) for which AB is less than or equal to B.

If AB is less than B, insert a new segment (B, N) after (AB, AN).

Find the last segment (YB, YN) for which YB is less than or equal to M.

Replace by (XB, N) any segment (XB, NOGROUP) for which XB is greater than B and less than YB.

If YN is not N, and either YN is NOGROUP or YB is less than or equal to B,

  Let (ZB, ZN) be the segment following (YB, YN).

  If M+1 is less than ZB, insert a new segment (M+1, YN)

    before (ZB, ZN).

Replace (YB, YN) by (YB, N).

Rewriting HTML Resources

As explained above with reference to **FIGURE 3** (B5), when a reflector or repeater serves a resource which itself includes resource identifiers (e.g., a HTML resource), that resource is modified (rewritten) to pre-reflect resource identifiers (URLs) of repeatable resources that appear in the resource. Rewriting ensures that when a browser requests repeatable resources identified by the requested resource, it gets them from a repeater without going back to the origin server, but when it requests non-repeatable resources identified by the requested resource, it will go directly to the origin server. Without this optimization, the browser would either make all requests at the origin server (increasing traffic at the origin server and necessitating far more redirections from the origin server), or it would make all requests at the repeater (causing the repeater to redundantly request and copy resources which could not be cached, increasing the overhead of serving such resources).

Rewriting requires that a repeater has been selected (as described above with reference to the Best Repeater Selector). Rewriting uses a so-called BASE directive. The BASE directive lets the HTML identify a different base server. (The base address is normally the address of the HTML resource.)

Rewriting is performed as follows:

F1. A BASE directive is added at the beginning of the HTML resource, or modified where necessary. Normally, a browser interprets relative URLs as being relative to the default base address, namely, the URL of the HTML resource (page) in which they are encountered. The BASE address added specifies the resource at the reflector which originally served the resource. This means that unprocessed relative URLs (such as

those generated by Javascript™ programs) will be interpreted as relative to the reflector. Without this BASE address, browsers would combine relative addresses with repeater names to create URLs which were not in the form required by repeaters (as described above in step D1).

F2. The rewriter identifies directives, such as embedded images and anchors, containing URLs. If the rewriter is running in a reflector, it must parse the HTML file to identify these directives.
If it is running in a repeater, the rewriter may have access to pre-computed information that identifies the location of each URL (placed in the HTML file in step F4).

F3. For each URL encountered in the resource to be re-written, the rewriter must determine whether the URL is repeatable (as in steps B1-B2). If the URL is not repeatable, it is not modified. On the other hand, if the URL is repeatable, it is modified to refer to the selected repeater.

F4. After all URLs have been identified and modified, if the resource is being served to a repeater, a table is appended at the beginning of the resource that identifies the location and content of each URL encountered in the resource. (This step is an optimization which eliminates the need for parsing HTML resources at the repeater.)

F5. Once all changes have been identified, a new length is computed for the resource (page). The length is inserted in the HTTP header prior to serving the resource.

An extension of HTML, known as XML, is currently being developed. The

process of rewriting URLs will be similar for XML, with some differences in the mechanism that parses the resource and identifies embedded URLs.

Handling Non-HTTP Protocols

This invention makes it possible to reflect references to resources that are served by protocols other than HTTP, for instance, the File Transfer Protocol (FTP) and audio/video stream protocols. However, many protocols do not provide the ability to redirect requests. It is, however, possible to redirect references before requests are actually made by rewriting URLs embedded in HTML pages. The following modifications to the above algorithms are used to support this capability.

In F4, the rewriter rewrites URLs for servers if those servers appear in a configurable table of cooperating origin server or so-called co-servers. The reflector operator can define this table to include FTP servers and other servers. A rewritten URL that refers to a non-HTTP resource takes the form:

http://<repeater>/<origin server>@proxy=<scheme>[:<type>]@/resource

where <scheme> is a supported protocol name such as "ftp". This URL format is an alternative to the form shown in B3.

In C3, the repeater looks for a protocol embedded in the arriving request. If a protocol is present and the requested resource is not already cached, the repeater uses the selected protocol instead of the default HTTP protocol to request the resource when serving it and storing it in the cache.

System Configuration and Management

In addition to the processing described above, the repeater network requires various mechanisms for system configuration and network management. Some of these mechanisms are described here.

Reflectors allow their operators to synchronize repeater caches by performing publishing operations. The process of keeping repeater caches synchronized is described below. Publishing indicates that a resource or collection of resources has changed.

Repeaters and reflectors participate in various types of log processing. The results of logs collected at repeaters are collected and merged with logs collected at reflectors, as described below.

Adding Subscribers to the Repeater Network

When a new subscriber is added to the network, information about the subscriber is entered in a Subscriber Table at the master repeater and propagated to all repeaters in the network. This information includes the *Committed Aggregate Information Rate* (CAIR) for servers belonging to the subscriber, and a list of the repeaters that may be used by servers belonging to the subscriber.

Adding Reflectors to the Repeater Network

When a new reflector is added to the network, it simply connects to and announces itself to a contact repeater, preferably using a securely encrypted certificate including the repeater's subscriber identifier.

The contact repeater determines whether the reflector network address is permitted for this subscriber. If it is, the contact repeater accepts the connection and updates the reflector with all necessary tables (using version numbers to determine which tables are out of date).

The reflector processes requests during this time, but is not "enabled" (allowed to reflect requests) until all of its tables are current.

Keeping Repeater Caches Synchronized

Repeater caches are coherent, in the sense that when a change to a resource is identified by a reflector, all repeater caches are notified, and accept the change in a single transaction.

Only the identifier of the changed resource (and not the entire resource) is transmitted to the repeaters; the identifier is used to effectively invalidate the corresponding cached resource at the repeater. This process is far more efficient than broadcasting the content of the changed resource to each repeater.

A repeater will load the newly modified resource the next time it is requested.

A resource change is identified at the reflector either manually by the operator, or through a script when files are installed on the server, or automatically through a change detection mechanism (e.g., a separate process that checks regularly for changes).

A resource change causes the reflector to send an "invalidate" message to its contact repeater, which forwards the message to the master repeater. The invalidate message contains a list of resource identifiers (or regular expressions identifying patterns of resource identifiers) that have changed. (Regular expressions are used to invalidate a directory or an entire server.) The repeater network uses a two-phase commit process to ensure that all repeaters correctly invalidate a given resource.

The invalidation process operates as follows:

The master broadcasts a "phase 1" invalidation request to all repeaters indicating the resources and regular expressions describing sets of resources to be invalidated.

When each repeater receives the phase 1 message, it first places the resource identifiers or regular expressions into a list of resource identifiers pending invalidation.

Any resource requested (in C3) that is in the pending invalidation list may not be served from the cache. This prevents the cache from requesting the resource from a peer cache which may not have received an invalidation notice. Were it to request a resource in this manner, it might replace the newly invalidated resource by the same, now stale, data.

The repeater then compares the resource identifier of each resource in its cache against the resource identifiers and regular expressions in the list.

Each match is invalidated by marking it stale and optionally removing it from the cache. This means that a future request for the resource will cause it to retrieve a new copy of the resource from the reflector.

When the repeater has completed the invalidation, it returns an acknowledgment to the master. The master waits until all repeaters have acknowledged the invalidation request.

If a repeater fails to acknowledge within a given period, it is disconnected from the master repeater. When it reconnects, it will be told to flush its entire cache, which will eliminate any consistency problem. (To avoid flushing the entire cache, the master could keep a log of all invalidations performed, sorted by date, and flush only files invalidated since the last time the reconnecting repeater successfully completed an invalidation. In the presently preferred embodiments this is not done since it is believed that repeaters will seldom disconnect.)

When all repeaters have acknowledged invalidation (or timed out) the repeater broadcasts a "phase 2" invalidation request to all repeaters. This causes the repeaters to remove the corresponding resource identifiers and regular expressions from the list of resource identifiers pending invalidation.

In another embodiment, the invalidation request will be extended to allow a "server push". In such requests, after phase 2 of the invalidation process has completed, the repeater receiving the invalidation request will immediately request a new copy of the invalidated resource to place in its cache.

Logs and Log Processing

Web server activity logs are fundamental to monitoring the activity in a Web site. This invention creates "merged logs" that combine the activity at reflectors with the

activity at repeaters, so that a single activity log appears at the origin server showing all Web resource requests made on behalf of that site at any repeater.

This merged log can be processed by standard processing tools, as if it had been generated locally.

On a periodic basis, the master repeater (or its delegate) collects logs from each repeater. The logs collected are merged, sorted by reflector identifier and timestamp, and stored in a dated file on a per-reflector basis. The merged log for a given reflector represents the activity of all repeaters on behalf of that reflector. On a periodic basis, as configured by the reflector operator, a reflector contacts the master repeater to request its merged logs. It downloads these and merges them with its locally maintained logs, sorting by timestamp. The result is a merged log that represents all activity on behalf of repeaters and the given reflector.

Activity logs are optionally extended with information important to the repeater network, if the reflector is configured to do so by the reflector operator. In particular, an "extended status code" indicates information about each request, such as:

1. request was served by a reflector locally;
2. request was reflected to a repeater;*
3. request was served by a reflector to a repeater;*
4. request for non-repeatable resource was served by repeater;*
5. request was served by a repeater from the cache;
6. request was served by a repeater after filling cache;
7. request pending invalidation was served by a repeater.

(The activities marked with "*" represent intermediate states of a request and do not normally appear in a final activity log.)

In addition, activity logs contain a duration, and extended precision timestamps. The duration makes it possible to analyze the time required to serve a resource, the bandwidth used, the number of requests handled in parallel at a given time, and other quite useful information. The extended precision timestamp makes it possible to

accurately merge activity logs.

Repeaters use the Network Time Protocol (NTP) to maintain synchronized clocks. Reflectors may either use NTP or calculate a time bias to provide roughly accurate timestamps relative to their contact repeater.

Enforcing Committed Aggregate Information Rate

The repeater network monitors and limits the aggregate rate at which data is served on behalf of a given subscriber by all repeaters. This mechanism provides the following benefits:

1. provides a means of pricing repeater service;
2. provides a means for estimating and reserving capacity at repeaters;
3. provides a means for preventing clients of a busy site from limiting access to other sites.

For each subscriber, a "threshold aggregate information rate" (TAIR) is configured and maintained at the master repeater. This threshold is not necessarily the committed rate, it may be a multiple of committed rate, based on a pricing policy.

Each repeater measures the information rate component of each reflector for which it serves resources, periodically (typically about once a minute), by recording the number of bytes transmitted on behalf of that reflector each time a request is delivered. The table thus created is sent to the master repeater once per period. The master repeater combines the tables from each repeater, summing the measured information of each reflector over all repeaters that serve resources for that reflector, to determine the "measured aggregate information rate" (MAIR) for each reflector.

If the MAIR for a given reflector is greater than the TAIR for that reflector, the MAIR is transmitted by the master to all repeaters and to the respective reflector.

When a reflector receives a request, it determines whether its most recently calculated MAIR is greater than its TAIR. If this is the case, the reflector

probabilistically decides whether to suppress reflection, by serving the request locally (in B2). The probability of suppressing the reflection increases as an exponential function of the difference between the MAIR and the CAIR.

Serving a request locally during a peak period may strain the local origin server, but it prevents this subscriber from taking more than allocated bandwidth from the shared repeater network.

When a repeater receives a request for a given subscriber (in C2), it determines whether the subscriber is running near its threshold aggregate information rate. If this is the case, it probabilistically decides whether to reduce its load by redirecting the request back to the reflector. The probability increases exponentially as the reflector's aggregate information rate approaches its limit.

If a request is reflected back to a reflector, a special character string is attached to the resource identifier so that the receiving reflector will not attempt to reflect it again. In the current system, this string has the form

"src=overload".

The reflector tests for this string in B2.

The mechanism for limiting Aggregate Information Rate described above is fairly coarse. It limits at the level of sessions with clients (since once a client has been reflected to a given repeater, the rewriting process tends to keep the client coming back to that repeater) and, at best, individual requests for resources. A more fine-grained mechanism for enforcing TAIR limits within repeaters operates by reducing the bandwidth consumption of a busy subscriber when other subscribers are competing for bandwidth.

The fine-grained mechanism is a form of data "rate shaping". It extends the mechanism that copies resource data to a connection when a reply is being sent to a client. When an output channel is established at the time a request is received, the repeater identifies which subscriber the channel is operating for, in C2, and records the subscriber in a data field associated with the channel. Each time a "write" operation is

about to be made to the channel, the Metered Output Stream first inspects the current values of the MAIR and TAIR, calculated above, for the given subscriber. If the MAIR is larger than the TAIR, then the mechanism pauses briefly before performing the write operation. The length of the pause is proportional to the amount the MAIR exceeds the TAIR. The pause ensures that tasks sending other resources to other clients, perhaps on behalf of other subscribers, will have an opportunity to send their data.

Repeater Network Resilience

The repeater network is capable of recovering when a repeater or network connection fails.

A repeater cannot operate unless it is connected to the master repeater. The master repeater exchanges critical information with other repeaters, including information about repeater load, aggregate information rate, subscribers, and link cost.

If a master fails, a "succession" process ensures that another repeater will take over the role of master, and the network as a whole will remain operational. If a master fails, or a connection to a master fails through a network problem, any repeater attempting to communicate with the master will detect the failure, either through an indication from TCP/IP, or by timing out from a regular "heartbeat" message it sends to the master.

When any repeater is disconnected from its master, it immediately tries to reconnect to a series of potential masters based on a configurable file called its "succession list".

The repeater tries each system on the list in succession until it successfully connects to a master. If in this process, it comes to its own name, it takes on the role of master, and accepts connections from other repeaters. If a repeater which is not at the top of the list becomes the master, it is called the "temporary master".

A network partition may cause two groups of repeaters each to elect a master. When the partition is corrected, it is necessary that the more senior master take over the

network. Therefore, when a repeater is temporary master, it regularly tries to reconnect to any master above it in the succession list. If it succeeds, it immediately disconnects from all of the repeaters connected to it. When they retry their succession lists, they will connect to the more senior master repeater.

To prevent losses of data, a temporary master does not accept configuration changes and does not process log files. In order to take on these tasks, it must be informed that it is primary master by manual modification of its successor list. Each repeater regularly reloads its successor list to determine whether it should change its idea of who the master is.

If a repeater is disconnected from the master, it must resynchronize its cache when it reconnects to the master. The master can maintain a list of recent cache invalidations and send to the repeater any invalidations it was not able to process while disconnected. If this list is not available for some reason (for instance, because the reflector has been disconnected too long), the reflector must invalidate its entire cache.

A reflector is not permitted to reflect requests unless it is connected to a repeater. The reflector relies on its contact repeater for critical information, such as load and Link Cost Tables, and current aggregate information rate. A reflector that is not connected to a repeater can continue to receive requests and handle them locally.

If a reflector loses its connection with a repeater, due to a repeater failure or network outage, it continues to operate while it tries to connect to a repeater.

Each time a reflector attempts to connect to a repeater, it uses DNS to identify a set of candidate repeaters given a domain name that represents the repeater network. The reflector tries each repeater in this set until it makes a successful contact. Until a successful contact is made, the reflector serves all requests locally. When a reflector connects to a repeater, the repeater can tell it to attempt to contact a different repeater; this allows the repeater network to ensure that no individual repeater has too many contacts.

When contact is made, the reflector provides the version number of each of its tables to its contact repeater. The repeater then decides which tables should be updated and sends appropriate updates to the reflector. Once all tables have been updated, the repeater notifies the reflector that it may now start reflecting requests.

Using a Proxy Cache within a Repeater

Repeaters are intentionally designed so that any proxy cache can be used as a component within them. This is possible because the repeater receives HTTP requests and converts them to a form recognized by the proxy cache.

On the other hand, several modifications to a standard proxy cache have been or may be made as optimizations. This includes, in particular, the ability to conveniently invalidate a resource, the ability to support cache quotas, and the ability to avoid making an extra copy of each resource as it passes from the proxy cache through the repeater to the requester.

In a preferred embodiment, a proxy cache is used to implement C3. The proxy cache is dedicated for use only by one or more repeaters. Each repeater requiring a resource from the proxy cache constructs a proxy request from the inbound resource request. A normal HTTP GET request to a server contains only the pathname part of the URL—the scheme and server name are implicit. (In an HTTP GET request to a repeater, the pathname part of the URL includes the name of the origin server on behalf of which the request is being made, as described above.) However, a proxy agent GET request takes an entire URL. Therefore, the repeater must construct a proxy request containing the entire URL from the path portion of the URL it receives. Specifically, if the incoming request takes the form:

GET /<origin server>/<path>

then the repeater constructs a proxy request of the form:

GET http://<origin server>/<path>

and if the incoming request takes the form:

GET <origin server>@proxy=<scheme>:<type>@/<path>

then the repeater constructs a proxy request of the form:

GET <scheme>://<origin server>/<path>

Cache Control

HTTP replies contain directives called cache control directives, which are used to indicate to a cache whether the attached resource may be cached and if so, when it should expire. A Web site administrator configures the Web site to attach appropriate directives. Often, the administrator will not know how long a page will be fresh, and must define a short expiration time to try to prevent caches from serving stale data. In many cases, a Web site operator will indicate a short expiration time only in order to receive the requests (or hits) that would otherwise be masked by the presence of a cache. This is known in the industry as "cache-busting". Although some cache operators may consider cache-busting to be impolite, advertisers who rely on this information may consider it imperative.

When a resource is stored in a repeater, its cache directives can be ignored by the repeater, because the repeater receives explicit invalidation events to determine when a resource is stale. When a proxy cache is used as the cache at the repeater, the associated cache directives may be temporarily disabled. However, they must be re-enabled when the resource is served from the cache to a client, in order to permit the cache-control policy (including any cache-busting) to take effect.

The present invention contains mechanisms to prevent the proxy cache within a repeater from honoring cache control directives, while permitting the directives to be served from the repeater.

When a reflector serves a resource to a repeater in B4, it replaces all cache directives by modified directives that are ignored by the repeater proxy cache. It does this by prefixing a distinctive string such as "wr-" to the beginning of the HTTP tag. Thus, "expires" becomes "wr-expires", and "cache-control" becomes "wr-cache-control". This prevents the proxy cache itself from honoring the directives. When a repeater serves a resource in C4, and the requesting client is not another repeater, it searches for HTTP tags beginning with "wr-" and removes the "wr-". This allows the clients retrieving the resource to honor the directives.

Resource Revalidation

There are several cases where a resource may be cached so long as the origin server is consulted each time it is served. In one case, the request for the resource is attached to a so-called "cookie". The origin server must be presented with the cookie to record the request and determine whether the cached resource may be served or not. In another case, the request for the resource is attached to an authentication header (which identifies the requester with a user id and password). Each new request for the resource must be tested at the origin server to assure that the requester is authorized to access the resource.

The HTTP 1.1 specification defines a reply header titled "Must-Revalidate" which allows an origin server to instruct a proxy cache to "revalidate" a resource each time a request is received. Normally, this mechanism is used to determine whether a resource is still fresh. In the present invention, Must-Revalidate makes it possible to ask an origin server to validate a request that is otherwise served from a repeater.

The reflector rule base contains information that determines which resources may be repeated but must be revalidated each time they are served. For each such resource, in B4, the reflector attaches a Must-Revalidate header. Each time a request comes to a repeater for a cached resource marked with a Must-Revalidate header, the request is forwarded to the reflector for validation prior to serving the requested resource.

Cache Quotas

The cache component of a repeater is shared among those subscribers that reflect clients to that repeater. In order to allow subscribers fair access to storage facilities, the cache may be extended to support quotas.

Normally, a proxy cache may be configured with a disk space threshold T. Whenever more than T bytes are stored in the cache, the cache attempts to find resources to eliminate.

Typically a cache uses the least-recently-used (LRU) algorithm to determine which resources to eliminate; more sophisticated caches use other algorithms. A cache may also support several threshold values—for instance, a lower threshold which, when reached, causes a low priority background process to remove items from the cache, and a higher threshold which, when reached, prevents resources from being cached until sufficient free disk space has been reclaimed.

If two subscribers A and B share a cache, and more resources of subscriber A are accessed during a period of time than resources of subscriber B, then fewer of B's resources will be in the cache when new requests arrive. It is possible that, due to the behavior of A, B's resources will never be cached when they are requested. In the present invention, this behavior is undesirable. To address this issue, the invention extends the cache at a repeater to support cache quotas.

The cache records the amount of space used by each subscriber in D_S, and supports a configurable threshold T_S for each subscriber.

Whenever a resource is added to the cache (at C3), the value D_S is updated for the subscriber providing the resource. If D_S is larger than T_S, the cache attempts to find resources to eliminate, from among those resources associated with subscriber S. The cache is effectively partitioned into separate areas for each subscriber.

The original threshold T is still supported. If the sum of reserved segments for each subscriber is smaller than the total space reserved in the cache, the remaining area is "common" and subject to competition among subscribers.

Note, this mechanism might be implemented by modifying the existing proxy cache discussed above, or it might also be implemented without modifying the proxy cache—if the proxy cache at least makes it possible for an external program to obtain a list of resources in the cache, and to remove a given resource from the cache.

Rewriting from Repeaters

When a repeater receives a request for a resource, its proxy cache may be configured to determine whether a peer cache contains the requested resource. If so, the proxy cache obtains the resource from the peer cache, which can be faster than obtaining it from the origin server (the reflector). However, a consequence of this is that rewritten HTML resources retrieved from the peer cache would identify the wrong repeater. Thus, to allow for cooperating proxy caches, resources are preferably rewritten at the repeater.

When a resource is rewritten for a repeater, a special tag is placed at the beginning of the resource. When constructing a reply, the repeater inspects the tag to determine whether the resource indicates that additional rewriting is necessary. If so, the repeater modifies the resource by replacing references to the old repeater with references to the new repeater.

It is only necessary to perform this rewriting when a resource is served to the proxy cache at another repeater.

Repeater-Side Include

Sometimes, an origin server constructs a custom resource for each request (for instance, when inserting an advertisement based on the history of the requesting client). In such a case, that resource must be served locally rather than repeated. Generally, a custom resource contains, along with the custom information, text and references to other, repeatable, resources.

The process that assembles a "page" from a text resource and possibly one or more image resources is performed by the Web browser, directed by HTML. However, it is not possible using HTML to cause a browser to assemble a page using text or directives from a separate resource. Therefore, custom resources often necessarily contain large amounts of static text that would otherwise be repeatable.

To resolve this potential inefficiency, repeaters recognize a special directive called a "repeater side include". This directive makes it possible for the repeater to assemble a custom resource, using a combination of repeatable and local resources. In this way, the static text can be made repeatable, and only the special directive need be served locally by the reflector.

For example, a resource X might consist of custom directives selecting an advertising banner, followed by a large text article. To make this resource repeatable, the Web site administrator must break out a second resource, Y, to select the banner. Resource X is modified to contain a repeater-side include directive identifying resource Y, along with the article. Resource Y is created and contains only the custom directives selecting an ad banner. Now resource X is repeatable, and only resource Y, which is relatively small, is not repeatable.

When a repeater constructs a reply, it determines whether the resource being served is an HTML resource, and if so, scans it for repeater-side include directives. Each such directive includes a URL, which the repeater resolves and substitutes in place of the directive. The entire resource must be assembled before it is served, in order to determine its final size, as the size is included in a reply header ahead of the resource.

Thus, a method and apparatus for dynamically replicating selected resources in computer networks is provided. One skilled in the art will appreciate that the present invention can be practiced by other than the described embodiments, which are presented for purposes of illustration and not limitation, and the present invention is limited only by the claims that follow.

What is claimed:

1. A method of processing resource requests in a computer network, the method comprising,

(i) by a client:

(A) making a request for a particular resource from an origin server, the request including a resource identifier for the particular resource;

(ii) by a reflector:

(B) intercepting the request from the client to the origin server;

(C) selecting a repeater to process the request;

(D) providing to the client a modified resource identifier designating the repeater;

(iii) by the client:

(E) receiving the modified resource identifier from the reflector; and

(F) making a request for the particular resource from the repeater designated in the modified resource identifier;

(iv) by the repeater:

(G) receiving the request from the client; and

(H) returning the requested resource to the client.

2. A method as in claim 1 further comprising, by the repeater:

(I) making a request for the resource from the origin server; and

(J) receiving the resource from the origin server.

3. A method as in claim 1 wherein the selecting of a repeater by the reflector comprises:

(C1) partitioning the network into groups;

(C2) determining which group the client is in;

(C3) selecting, from a plurality of repeaters in the network, a set of repeaters having a lowest cost relative to the group which the client is in; and

(C4) selecting as the repeater a member of the selected set of repeaters.

4. A method as in claim 3, wherein the cost of a repeater is a value based on that repeater's current load and a maximum load for that repeater.

5. A method as in claim 3, wherein the cost of a repeater is a value based on a predicted cost or speed of transmission between the repeater and a client in the group.

6. A method as in claim 1 wherein the particular resource itself contains at least one other resource identifier of at least one other resource, the method further comprising:

rewriting the particular resource to replace at least some of the resource identifiers contained therein with modified resource identifiers designating a repeater instead of the origin server.

7. A method as in claim 6 wherein the rewriting is performed by one of the repeater, the reflector or another repeater.

8. A method of processing resource requests in a computer network, the method comprising,

(i) by a client:

(A) making a request for a particular resource from an origin server, the request including a resource identifier for the particular resource;

(ii) by a reflector:

(B) intercepting the request from the client to the origin server;

(C) determining whether to reflect the request to a repeater;

(D) when the reflector determines not to reflect the request, forwarding the request to the origin server, otherwise

(D1) selecting a repeater to process the request;

(D2) providing to the client a modified resource identifier designating the repeater.

9. A method as in claim 8, further comprising, when the reflector determines to reflect the request,

(iii) by the client:

(E) receiving the modified resource identifier from the reflector; and

(F) making a request for the particular resource from the repeater designated in the modified resource identifier;

(iv) by the repeater:

(G) receiving the request from the client; and

(H) returning the requested resource to the client.

10. A method as in claim 8 wherein the reflector determines whether to reflect a request by comparing the resource identifier with regular expression patterns of repeatable resources.

11. A method as in claim 8, wherein the reflector has a threshold aggregate information rate (TAIR) associated therewith, and wherein the determining of whether to reflect the request to a repeater comprises:

determining whether the TAIR of the reflector is exceeded by a measured aggregate information rate (MAIR) for the reflector, wherein the reflector determines not to reflect the request when the MAIR exceeds the TAIR for the reflector.

12. A method as in claim 8, wherein the reflector has a threshold aggregate information rate (TAIR) associated therewith, and wherein the determining of whether to reflect the request to a repeater comprises:

probabilistically determining whether the TAIR of the reflector is exceeded by a measured aggregate information rate (MAIR) for the reflector, wherein the reflector determines not to reflect the request as an exponential function of the difference between the MAIR and the TAIR.

13. A method as in any of claims 11-12, wherein the MAIR is obtained from repeaters according to the rate at which they have transmitted data on behalf of the reflector during a given time interval.

14. A method as in any one of claims 1-12 wherein the network is the Internet and wherein the resource identifier is a uniform resource locator (URL) for designating resources on the Internet, and wherein the modified resource identifier is a URL designating the repeater and indicating the reflector or origin server, and wherein the modified resource identifier is provided to the client using a REDIRECT message.

15. In a computer network wherein clients request resources from origin servers, a method comprising:

providing at least one repeater;

providing reflectors at some of the origin servers, each reflector intercepting client resource requests made to its respective origin server; and

each reflector selectively redirecting client resource requests for certain resources to one of the repeaters.

16. A method as in claim 15 further comprising, by repeaters in the network:

servicing redirected client resource requests; and

selectively maintaining copies of requested resources,

whereby resources corresponding to redirected resource requests are selectively migrated from their origin servers to one or more repeaters.

17. A computer network comprising:

a plurality of origin servers, at least some of the origin servers having reflectors associated therewith;

a plurality of repeaters; and

a plurality of clients,

wherein each reflector is adapted to intercept resource requests made to its respective origin server and to selectively redirect the resource requests to a dynamically selected repeater.

18. In a computer network wherein clients request resources from origin servers, a reflector mechanism associated with an origin server, the reflector mechanism comprising:

means for intercepting a resource request made by client of an origin server;

means for analyzing the resource request to determine whether to service the request locally at the origin server;

means for determining a best repeater in the network to service the request when

the analyzing means determines that the request should not be serviced locally; and

means for redirecting the client to the best repeater.

19. A reflector mechanism as in claim 18 wherein the network is partitioned into groups and the means for determining the best repeater comprises:

means for determining which group the client is in;

means for selecting, from a plurality of repeaters in the network, a set of repeaters having a lowest cost relative to the group the client is in; and

means for selecting as the best repeater a member of the set of repeaters.

20. A reflector mechanism as in claim 19, wherein the cost of a repeater is a value based on a predicted cost or speed of transmission between the repeater and a client in the group.

21. A mechanism as in claim 19, wherein the cost of a repeater is a value based on that repeaters current load and a maximum load for that repeater.

22. A reflector as in claim 16 wherein the resource itself contains resource identifiers, the reflector further comprising:

means for rewriting the resource to replace at least some of the resource identifiers contained therein with modified resource identifiers designating the repeater instead of the origin server.

23. In a computer network wherein clients request resources from origin servers, a repeater mechanism comprising:

means for receiving a resource request from a client;

means for determining whether the resource is available locally;

means for, when it is determined that the resource is not available locally,

obtaining the resource from an origin server; and

means for providing the resource to the client.

24. A reflector as in claim 18 wherein the resource itself contains resource identifiers, the repeater further comprising:

means for rewriting the resource to replace at least some of the resource identifiers contained therein with modified resource identifiers designating the repeater instead of the origin server.

ABSTRACT OF THE INVENTION

OPTIMIZED NETWORK RESOURCE LOCATION

Resource requests made by clients of origin servers in a network are intercepted by reflector mechanisms and selectively reflected to other servers called repeaters. The reflectors select a best repeater from a set of possible repeaters and redirect the client to the selected best repeater. The client then makes the request of the selected best repeater. The resource is possibly rewritten to replace at least some of the resource identifiers contained therein with modified resource identifiers designating the repeater instead of the origin server.

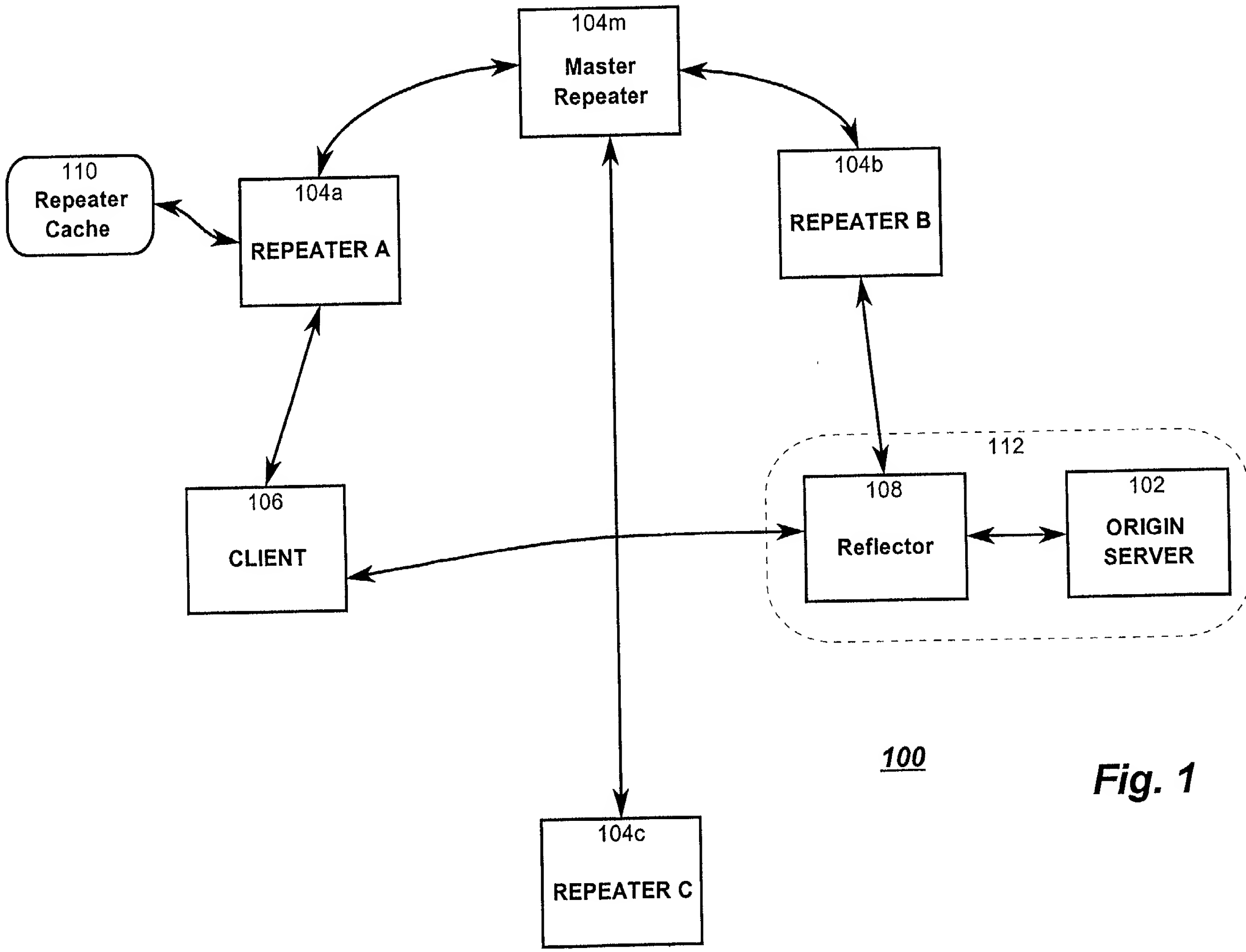

104m
Master Repeater
110
Repeater Cache
104a
REPEATER A
104b
REPEATER B
106
CLIENT
112
108
Reflector
102
ORIGIN SERVER
104c
REPEATER C
100

Fig. 1

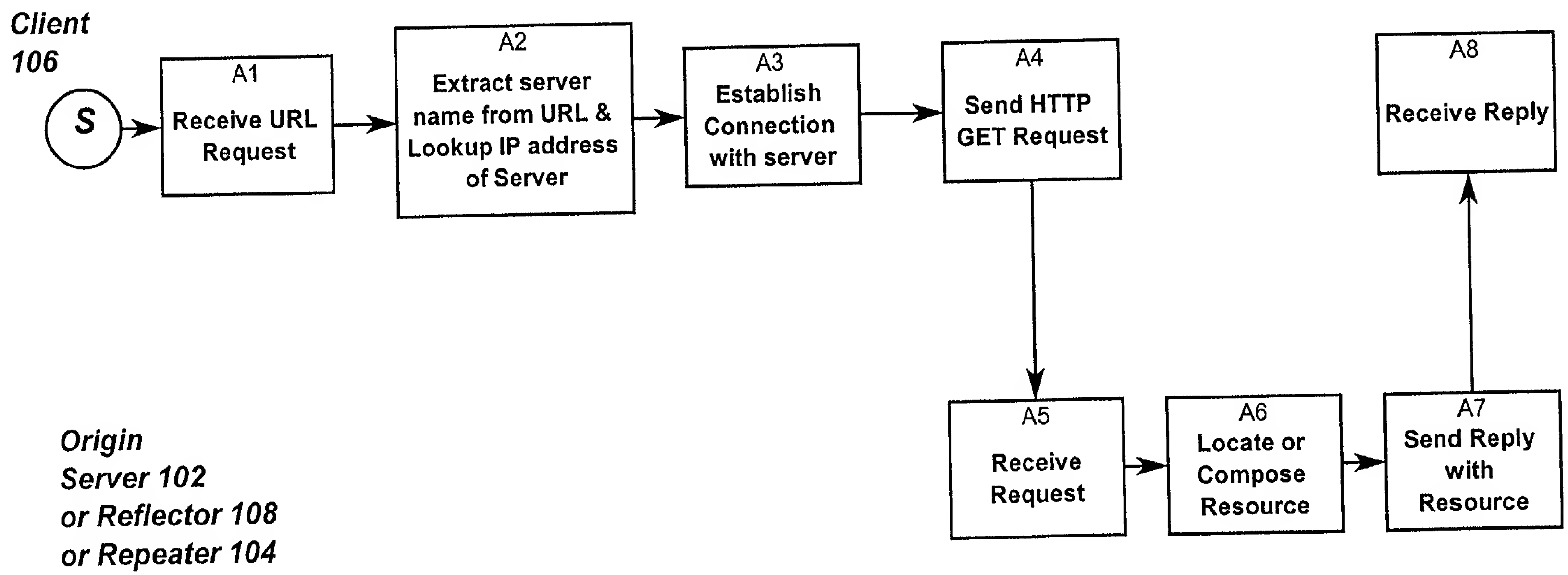
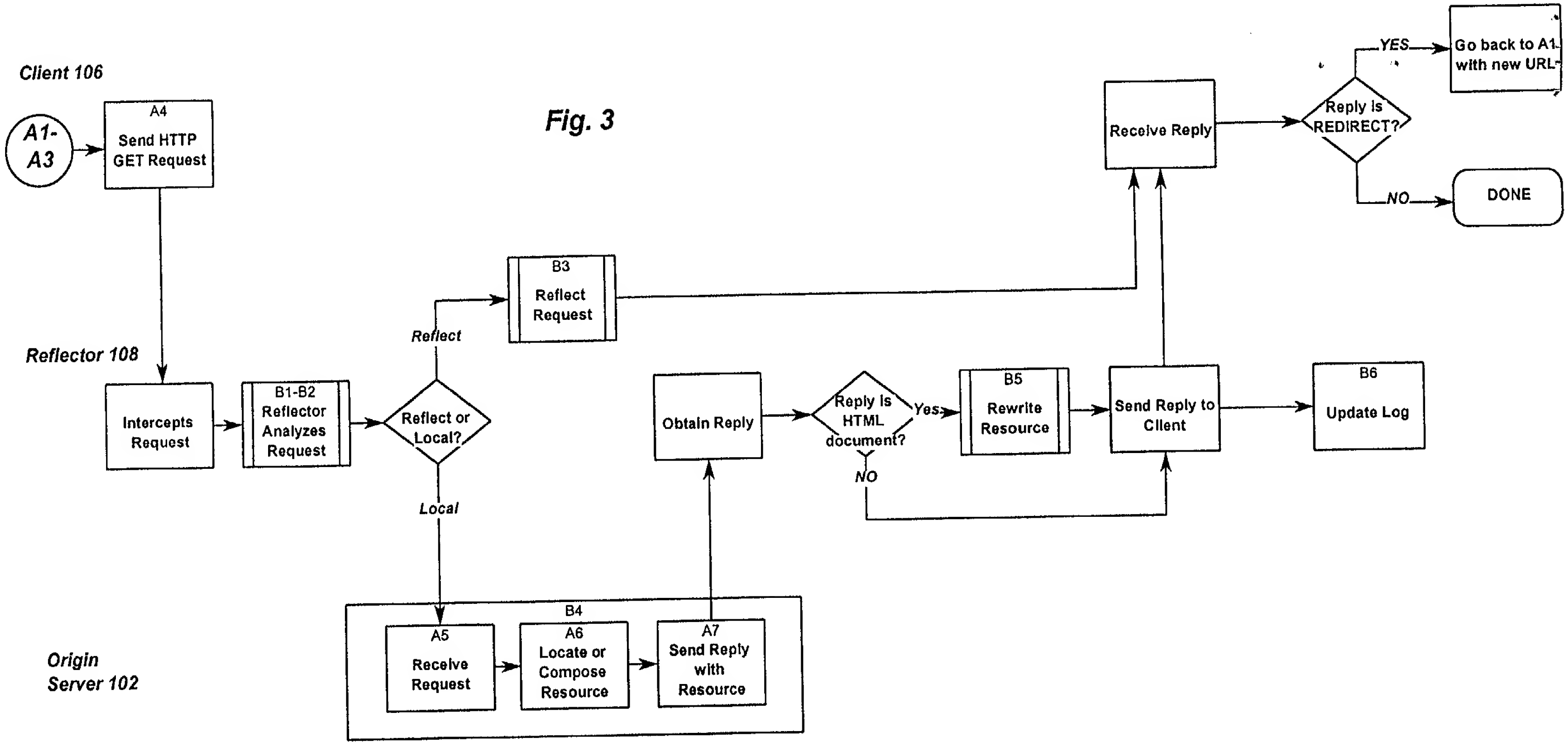

Client
106
S
A1
Receive URL Request
A2
Extract server name from URL & Lookup IP address of Server
A3
Establish Connection with server
A4
Send HTTP GET Request
A8
Receive Reply
Origin
Server 102
or Reflector 108
or Repeater 104
A5
Receive Request
A6
Locate or Compose Resource
A7
Send Reply with Resource

Fig. 2

Fig. 3



Client 106
A1-A3
A4
Send HTTP GET Request
Reflector 108
Intercepts Request
B1-B2
Reflector Analyzes Request
Reflect or Local?
Reflect
Local
B3
Reflect Request
Origin Server 102
B4
A5
Receive Request
A6
Locate or Compose Resource
A7
Send Reply with Resource
Obtain Reply
Reply is HTML document?
Yes
NO
B5
Rewrite Resource
Send Reply to Client
B6
Update Log
Receive Reply
Reply is REDIRECT?
YES
Go back to A1 with new URL
NO
DONE

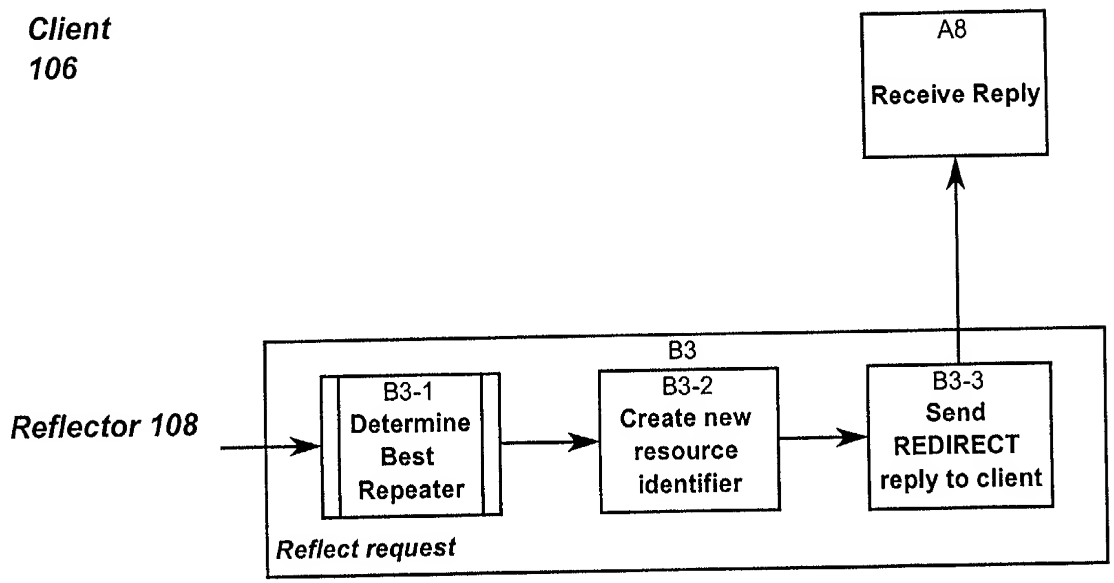

Client
106
A8
Receive Reply
Reflector 108
B3
B3-1
Determine
Best
Repeater
B3-2
Create new
resource
identifier
B3-3
Send
REDIRECT
reply to client
Reflect request

Fig. 4

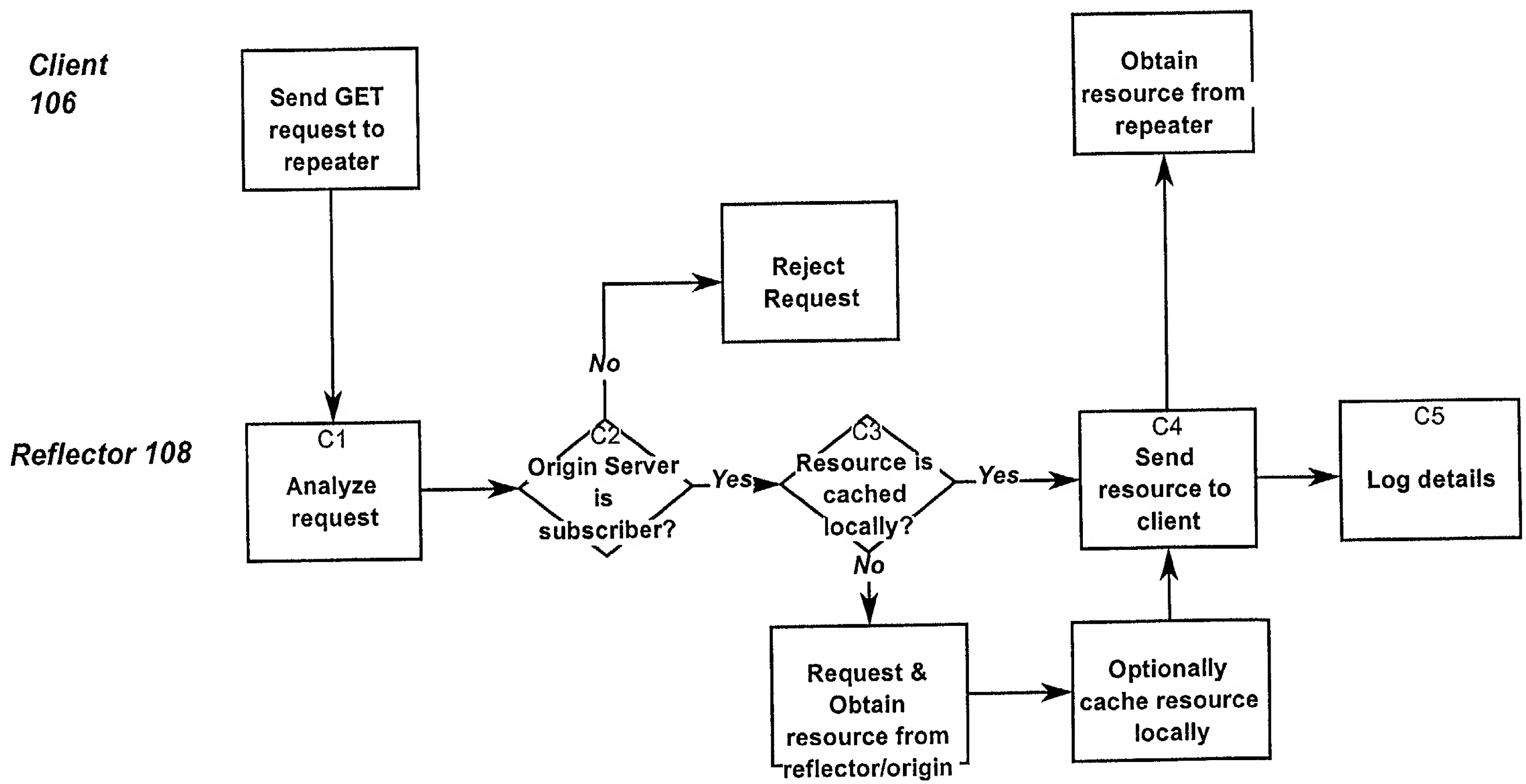

Client
106
Reflector 108
Send GET request to repeater
C1
Analyze request
C2
Origin Server is subscriber?
No
Reject Request
Yes
C3
Resource is cached locally?
No
Request & Obtain resource from reflector/origin
Yes
C4
Send resource to client
Optionally cache resource locally
Obtain resource from repeater
C5
Log details

Fig. 5

Reflector 108

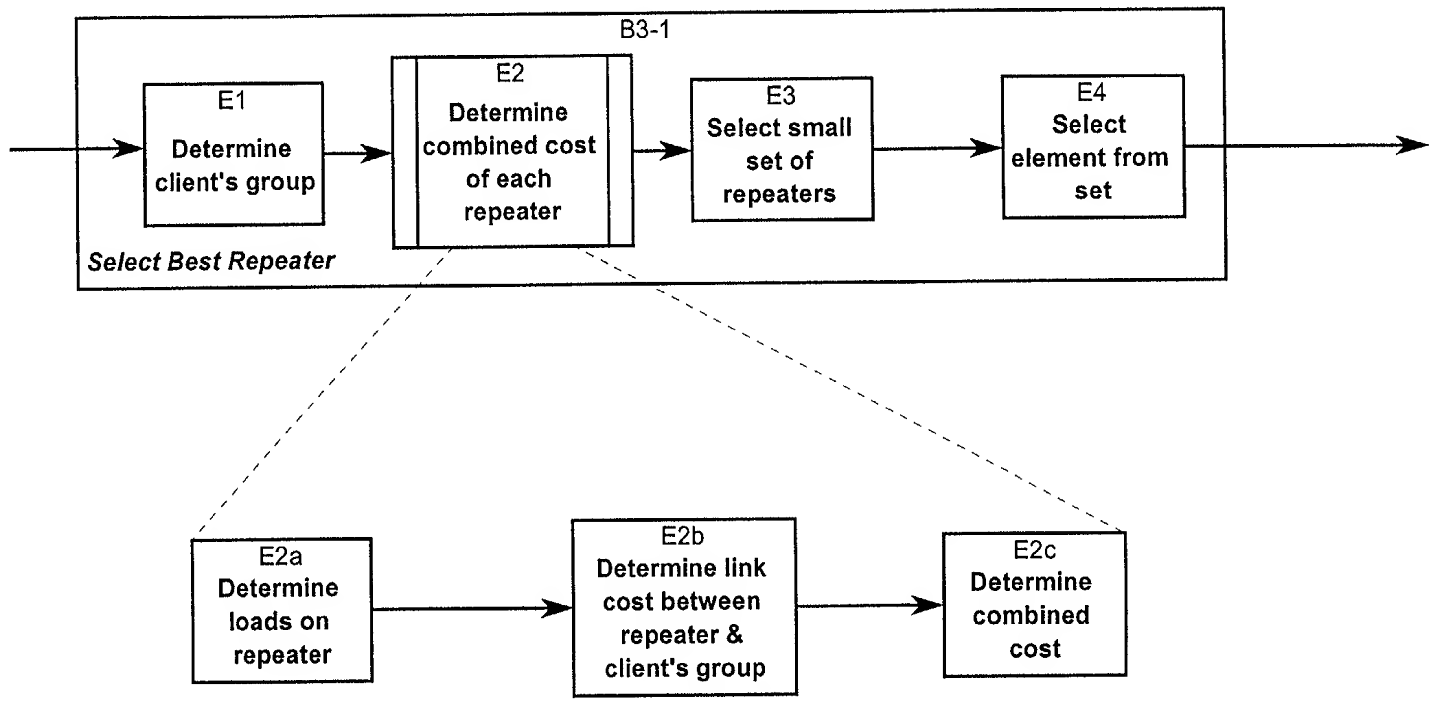


Fig. 6

FOR UTILITY/DESIGN CIP/PCT NATIONAL/PLANT ORIGINAL/SUBSTITUTE/SUPPLEMENTAL DECLARATIONS	RULE 63 (37 C.F.R. 1.63) DECLARATION AND POWER OF ATTORNEY FOR PATENT APPLICATION IN THE UNITED STATES PATENT AND TRADEMARK OFFICE	CUSHMAN FORM

As a below named inventor, I hereby declare that my residence, post office address and citizenship are as stated below next to my name, and I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the INVENTION ENTITLED OPTIMIZED NETWORK RESOURCE LOCATION

the specification of which (CHECK applicable BOX(ES))
X → ☐ is attached hereto.
BOX(ES) → ☒ was filed on February 10, 1998 as U.S. Application No. /
→ → ☐ was filed as PCT International Application No. PCT/ / on
and (if applicable to U.S. or PCT application) was amended on

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above. I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56. I hereby claim foreign priority benefits under 35 U.S.C. 119/365 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate filed by me or my assignee disclosing the subject matter claimed in this application and having a filing date (1) before that of the application on which priority is claimed, or (2) if no priority claimed, before the filing date of this application:

PRIOR FOREIGN APPLICATION(S) Number	Country	Day/MONTH/Year Filed	Date first Laid-open or Published	Date Patented or Granted	Priority Claimed Yes	No

I hereby claim domestic priority benefit under 35 U.S.C. 119/120/365 of the indicated United States applications listed below and PCT international applications listed above or below and, if this is a continuation-in-part (CIP) application, insofar as the subject matter disclosed and claimed in this application is in addition to that disclosed in such prior applications, I acknowledge the duty to disclose all information known to me to be material to patentability as defined in 37 C.F.R. 1.56 which became available between the filing date of each such prior application and the national or PCT international filing date of this application:

PRIOR U.S. PROVISIONAL, NONPROVISIONAL AND/OR PCT APPLICATION(S) Application No. (series code/serial no.)	Day/MONTH/Year Filed	Status pending, abandoned, patented	Priority Claimed Yes	No

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

And I hereby appoint Pillsbury Madison & Sutro LLP, Intellectual Property Group, 1100 New York Avenue, N.W., Ninth Floor, East Tower, Washington, D.C. 20005-3918, telephone number (202) 861-3000 (to whom all communications are to be directed), and the below-named persons (of the same address) individually and collectively my attorneys to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith and with the resulting patent, and I hereby authorize them to delete names/numbers below of persons no longer with their firm and to act and rely on instructions from and communicate directly with the person/assignee/attorney/firm/ organization who/which first sends/sent this case to them and by whom/which I hereby declare that I have consented after full disclosure to be represented unless/until I instruct the above Firm and/or a below attorney in writing to the contrary.

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	City	State/Foreign Country	Country of Citizenship
Post Office Address			
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	City	State/Foreign Country	Country of Citizenship
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Residence			
	City	State/Foreign Country	Country of Citizenship
Post Office Address			
(include Zip Code)			